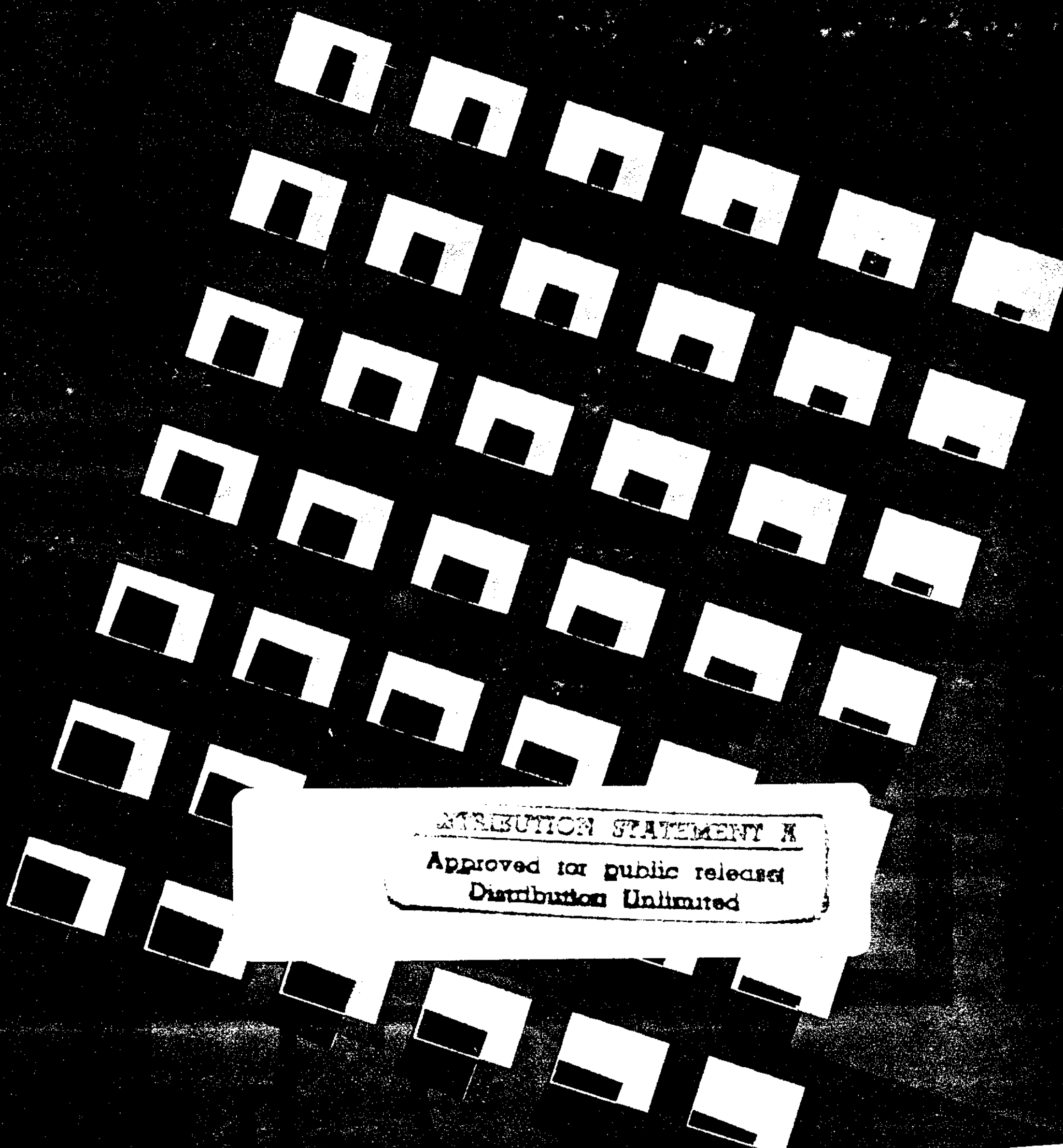
TNO-report
TNO-TM 1995 A-54

title
An ECDIS/Track Predictor prototype on top of the GEO^{++} system

TNO Human Factors
Research Institute



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Under contract to the Royal Netherlands Navy (contract no. A90/KM/332), the TNO Human Factors Research Institute investigates new user-interface concepts for ECDIS-based navigation support systems. On the basis of a two-stage description of track planning, a user interface has been designed for an integrated ECDIS/track-prediction system which assists the master in the preparation of manoeuvres. Both ECDIS display and track-prediction interface conform to existing specifications (IHO respectively OSF/Motif), so that the interface can be integrated with existing (commercial) ECDIS systems.
Regarding further research, it is recommended to focus attention on the information presentation during the execution of a manoeuvre, in order to assist the master in a fast detection of deviations between predictions and observations on the basis of which feedback corrections can be determined.

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Het Koninklijk Instituut voor de Marine (KIM) is geïnteresseerd in het ontwerp en de integratie van additionele navigatie-hulpmiddelen in toekomstige ECDIS (Electronic Chart Display) systemen. Een specifiek voorbeeld is baanvoorspelling.
Het ontwerp van een mens-machine interface voor een baanvoorspeller module bovenop een ECDIS (Electronic Chart Display).
De ECDIS kaartachtergrond dient te voldoen aan de door de IHO (International Hydrographic Organization) gedicteerde richtlijnen betreffende kleurgebruik en symboliek. Er zal worden beschreven hoe deze richtlijnen in de praktijk gebruikt kunnen worden. De ontworpen interface dient verder toegepast te kunnen worden in bestaande (commerciële) ECDIS systemen. Hiertoe is gebruikt gemaakt van mens-machine interface componenten uit de standaard grafische OSF/Motif omgeving.
Aangetoond is dat rekening houdend met de IHO en Motif richtlijnen een baanvoorspeller interface ontworpen en geprototyped kan worden. Aanbevolen wordt in het kader van verder onderzoek de aandacht te richten op de informatiepresentatie tijdens de uitvoering van een manoeuvre, teneinde een snelle detectie van afwijkingen tussen voorspellingen en observaties te bewerkstelligen op basis waarvan stuurcorrecties kunnen worden bepaald.

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Institute: TNO Human Factors Research Institute
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SUMMARY

Under contract to the Royal Netherlands Navy (contract no. A90/KM/332), the TNO Human Factors Research Institute investigates new user-interface concepts for ECDIS-based navigation support systems. On the basis of a two-stage description of track planning, a user interface has been designed for an integrated ECDIS/track-prediction system which assists the master in the preparation of manoeuvres. Both ECDIS display and track-prediction interface conform to existing specifications (IHO respectively OSF/Motif), so that the interface can be integrated with existing (commercial) ECDIS systems.
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TNO Technische Menskunde
Soesterberg

Een ECDIS/Baanpredictor prototype op het GEO^{++} SYSTEEM

C. Vijlbrief en P.O. Passenier

SAMENVATTING

In opdracht van de Koninklijke Marine (A90/KM/332) worden nieuwe interfaceconcepten onderzocht voor ECDIS gebaseerde systemen voor navigatie-ondersteuning. Op basis van een twee-niveaus beschrijving van het track planning proces is een gebruikersinterface ontworpen voor een geïntegreerd ECDIS/baanpredictiesysteem voor de ondersteuning van de voorbereiding van manoeuvres. Zowel het ECDIS display als de gebruikersinterface van de baanvoorspeller zijn ontworpen conform bestaande richtlijnen (IHO respectievelijk OSF/Motif), zodat de gebruikersinterface kan worden geïntegreerd met bestaande (commerciële) ECDIS systemen.

Aanbevolen wordt in het kader van verder onderzoek de aandacht te richten op de informatiepresentatie tijdens de uitvoering van een manoeuvre, ten einde een snelle detectie van afwijkingen tussen voorspellingen en observaties te bewerkstelligen op basis waarvan stuurcorrecties kunnen worden bepaald.

1 INTRODUCTION

1.1 Aim of the study

Under contract to the Royal Netherlands Navy (contract nr. A90/KM/332), the TNO Human Factors Research Institute investigates user-interface aspects of the integration of a track-prediction module in ECDIS systems. The 'Koninklijk Instituut voor de Marine' (KIM, The Dutch Royal Navy Institute) is interested in the design and integration of additional navigational tools into future ECDIS (Electronic Chart Display) systems. A specific example is the implementation of a track-prediction module, under development at the Royal Navy Institute, in an ECDIS system for track-planning purposes. This report describes the design of the user interface.

1.2 Background

Ship navigation is a hierarchically ordered process of control activities (Kelley, 1968); a planning, monitoring and control level can be distinguished. At the highest level the master is planning the passage. This level mainly consists of decision making based upon information from different sources. At the intermediate level the manoeuvring process is monitored in order to anticipate deviations between the ship's future path and the planned route. At the lowest level the expected track deviations are minimized. On these various levels automatons may be applied to effectively support the human operator, ranging from decision support systems (at the planning level) to adaptive autopilots at the control level. This expansion of automation converts the bridge to an operational centre for both navigational and supervisory tasks.

Due to the spatial nature of decision-making problems related to navigation, spatial integration of available data (e.g. weather, waves, route) on the basis of a map-based (ECDIS) presentation format—resulting in a maritime Geographic Information System (GIS)—is considered to be a promising starting point for support at the planning level (Fawcett et al., 1992). In this way the planned route may be optimized with regard to different criteria as fuel consumption and travelling time.

Van Oosterom and Vijlbrief (1994) gave a framework for integrating complex spatial analyses functions in an open Geographic Information System. For this purpose two different aspects of integration are described: integration of the user interface and the data sharing between analyses functions and the GIS. A solution is proposed based on the extensible GIS called 'GEO^{++}' (Vijlbrief & van Oosterom, 1992).

Information on the monitoring level concerns the ship's position and movement status such as heading, rate of turn, ground velocity of own ship and other vessels on the radar screen. To improve the master's anticipating capabilities and thus the resulting accuracy of ship control, a track-prediction system could be useful. Previous research on this topic ranges from extrapolation methods (Bernotat, 1971) to prediction on the basis of a mathematical model of the process to be controlled (Kelley, 1968). More practical studies to demonstrate the possible advantages of track prediction for the accurate control of the ship's motions have been carried out a.o. by Van Berlekom (1977) and Passenier (1989). In the latter case, integration of an on-line track-prediction system with an adaptive course controller (Van

Amerongen, 1982) was taken as a starting point. On the basis of this approach, a simulator experiment (Van Breda & Schuffel, 1988) showed a reduction in tracking error to 30% when compared to more conventional navigation methods like parallel indexing (Shell, 1975; Spaans, 1979a) or a ground speed vector (Sheridan, 1966).
For the present study a possible integration is investigated of a track-prediction system, under development at the Royal Navy Institute, with a Geographic Information System. The track-prediction system is based on a ship manoeuvring model as implemented by Wulder (1992) in an integrated navigation system. The prediction system is intended to assist the master in the short-term planning of, for instance, harbouring manoeuvres by providing him information on the basis of 'wheel-over-point' calculations.

1.3 Approach

The following considerations are taken into account for the design of the track predictor user interface:

- the ECDIS map serves merely to create the necessary background for the track predictor and is not considered to be part of the proposed interface. The used colours and hydrographic symbol shapes are dictated by the IHO (International Hydrographic Organization) standards. We will describe how we adhered to these standards. We have not seen presentations of any other commercial or research ECDIS systems which implement the IHO specifications, so the description of the ECDIS visualization scheme is an important part of this report.
- the proposed track-predictor interface should apply standard OSF/Motif interface components whenever possible, so that the interface can be integrated with existing (commercial) ECDIS systems. Note that this condition limits the application of a dedicated direct-manipulation interface in which the user interacts directly by means of the pointing device with a graphical symbolization of the simulated vessel. In the Motif interface input of e.g. steering parameters is provided by means of sliders.

In this report we will describe the prototype implementation built on top of the GEO^{++} system (Van Oosterom & Vijlbrief, 1991, 1994; Vijlbrief & Van Oosterom, 1992). The specific user interface components were developed on the TNO-TM in-house 'Builder' user-interface development environment (Vijlbrief, 1994), which results in an interface with the required Motif (Open Software Foundation, 1991) look and feel. Chapter 2 discusses the components relating to the ECDIS functionality in detail. The design of the track-predictor interface will be discussed in Chapter 3.

2 THE ECDIS PROTOTYPE

2.1 ECDIS requirements

Most commercial ECDIS systems available today do not conform to IHO specifications for ECDIS systems. There are in general two classes of commercial systems:

- raster-based systems: these display scanned paper nautical charts.
- vector-based systems: these draw nautical charts from data stored in some kind of data storage system.

The raster-based systems have as an advantage that paper nautical charts are used, so data conversion and availability is a minor issue. Corresponding disadvantages to this approach are that colour adaption (e.g. depending on the level of light on the bridge switching between a day and night colour scheme), and other corrections (like incremental map modifications) are often not possible. The vector-based systems can easily adapt to changed visualization criteria but they display data from vector databases which are not always available (yet). The official standard for these vector databases is the IHO DX-90 standard (IHO, 1991).

The IHO specifications describe vector-based ECDIS systems. These specifications take the form of an IHO supplied Colours & Symbols Presentation Library. This library (IHO, 1990, 1992) contains in a machine readable format a description of the colours, symbols and line, c.q. area patterns to be used. Most commercial suppliers of vector-based ECDIS systems currently use their own symbol definitions and colour coding, in addition to their own vector database specifications (no DX-90). In this chapter we will describe how we configured our GEO^{++} system to handle the DX-90 data and how to visualize this data according to IHO specifications. The corresponding system architecture is presented in Fig. 1. The different components will be described in more detail in the next sections.

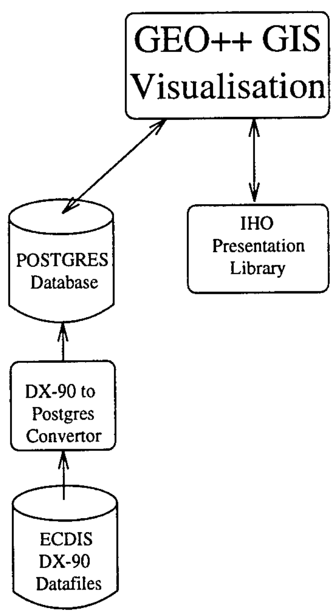

Fig. 1 System architecture for the ECDIS system.

2.2 ECDIS DX-90 Datafiles

The basis of the ECDIS prototype are DX-90 data files describing the objects on a nautical chart. DX-90 (IHO, 1991) is an international standard which lists all the different features (object types) and their attributes, and the format in which these are specified in the data

files. Examples of features and corresponding attributes are (see Appendix A for a more complete list):

- *Point Features:*

lights:	attributes specify e.g. colour and blinking frequency.
wrecks:	attributes specify e.g. ship name and wreck category.
symbols:	attributes specify cartographic representation, e.g. a textual label and a rotation.

- *Line Features:*

depth contours:	attributes specify depth and a polyline (a number of locations composing a line).
rivers:	attributes specify the name and a polyline. Note that in general rivers specified as a line will be small. Important rivers will be specified as an area.
recommended track:	attributes specify an optional name, a track category, a polyline, etc.

The ECDIS DX-90 data used for this prototype is the NL-122 sea chart. This data was provided by the Dutch Hydrographic Service. It covers the 'Eurogeul' area: the entrance to the Rotterdam harbour.

2.3 DX-90 to Postgres Converter

The objects stored in the DX-90 datafiles are not directly suitable for storage in a relational database system. They first have to be converted to a format specifying each individual tuple for the relations (or less formally: tables) used in the Postgres database. For instance, to store the DX-90 *Point Features*, the following relations (with their attributes) are used (see Appendix A for a more complete list):

Points:

ObjId:	contains the object identification as assigned by the Hydrographic Service, e.g. FE5AF 1059.
ObjL:	contains the object label, e.g. WRECKS.
Attr:	contains the attribute information, e.g. OBJNAMSperrbrecher147, CATWRK2, VERDAT2, QUASOU1, TECSOU6, VALSOU11.2, SCAMIN50000, SCAMAX50000, SORDAT7-JUL-1992, RECINDNHS-DIGI, RECDAT7-JUL-1992 which lists a lot of specific additional information. See the official IHO documents for details.
Pnt2:	contains the position in geographical long/lat coordinates, e.g. (4.086945, 52.026108).
Geo_bbox:	contains the minimal bounding box of the feature, e.g. (4.08695, 52.0261, 4.08695, 52.0261) This is used by GEO^{++} to zoom quickly to specific locations on the ECDIS map.

2.4 IHO Presentation Library

The IHO supplies a Colours & Symbols Presentation Library. This library (IHO, 1990, 1992) contains in a machine readable format a description of the colours, symbols and line, c.q. area patterns to be used in a conforming ECDIS implementation. The preliminary

version (version 0.9, December 1992) used for the ECDIS prototype described in this report did not include a description for area patterns, so this feature could not be implemented.

Colours

The IHO colour specification contains the following information:
- the symbolic colour code, e.g. 'NODTA' is the colour to be used when no data is available for a specific area
- the colour, e.g. 'moss green'
- the x, y and luminance values in the CIE Colour Space
- an approximation of the colour in RGB values.

A part of the colour specifications is given in Appendix B.

Dictionaries

The presentation library contains dictionaries (lookup tables) which specify the visualization for point, line and area features. We will give a short explanation of the visualization specification for points only. The specifications for lines and areas are similar. The specification for points contains the following information (see Appendix B):
- the code of the object (point feature) class, e.g. 'ACHARE' is an Anchorage Area.
- the attribute combination, e.g.: 'BCNSHP2!MARSYS1!CATLAM1!', means that the symbolization instruction for objects of type 'BCNLAT' (beacon, lateral) is only valid when the point feature has all the listed attributes.
- the symbolization instruction. It is either of the form 'SY(XXX)' (e.g. 'SY(HULKES01)'), which means to draw a specific symbol according to symbol definition 'XXX' (see *Symbol definitions*); or of the form 'CS(YYY)' (e.g. 'CS(LIGHTS00)'), which means to draw a specific symbol according to the symbology procedure 'YYY' (see *Symbology procedures*).
- the display priority, a 4 digit integer number.
- the viewclass membership (optional), it is either empty, standard or supplement.

Symbol definitions

The IHO Presentation Library specifies the drawing definitions for symbols in a machine readable form. For each of the possible 'SY(XXX)' instructions the library contains a definition. The actual drawing instructions form part of this definition, which steer a 'virtual plotting engine' (see Appendix B).

Symbology procedures

In the used version of the Presentation Library the Conditional Symbology Procedures were not supplied in machine readable form yet. Instead the specification is given in the form of Nassi & Shneiderman diagrams (German Standard Institute, undated). These diagrams show the decision tree which, when traversed, results in a correct visualization (see Appendix B for an example). Whether a specific branch is taken depends in most cases on the value of certain feature attributes.

2.5 GEO^{++} ECDIS visualization

Visualization of the ECDIS data is done by means of the GEO^{++} system. The GEO^{++} system displays geographic data on the basis of a number of map layers. Each map layer corresponds to a relation (table) in the database used. The ECDIS prototype displays the following layers (some may be hidden by the user): *'depth areas', 'areas', 'cartol', 'lines', 'cartop', 'soundings', 'points'.* See Appendix A for details on these layers. Specifications from the IHO Presentation Library (see § 2.4 and Appendix B) are also stored in database relations.

The GEO^{++} system allows visualization of arbitrary complex database data by means of the definition of 'Query-Shapes'. By designing and defining 'Query-Shapes' which comply with Presentation Library conventions (e.g. the 'virtual plotting engine' described in Appendix B) the system is able to visualize the data according to the official SP-52 standard.

Symbology Procedures are not yet supplied in machine readable form so every procedure would have to be coded by hand. This is done for the 'LIGHTS' and 'DEPARE' (Depth Area) procedures. Other procedures will be coded when the need arises.

Fig. 2 shows the GEO^{++} visualization of ECDIS data, with in the upper right corner an overview map display. The ECDIS map in the left part of the window shows the Rotterdam Eurogeul area. The 20 meter safety contours and the corresponding shallow and deep depth areas are clearly visible. In addition the land areas, wrecks, boys and lights are shown.

In the northern part of the ECDIS chart the simulated own ship symbol is visible and a predicted track (bending south wards) is shown. Also note that three scale objects are placed on top of the ECDIS chart. The upper scale shows the current heading of the simulated vessel. The lower scale shows the current rudder setpoint and the right scale shows the ship's forward speed in knots. Details on the track predictor will be given in Chapter 3.

2.6 Discussion

The ECDIS prototype demonstrates the feasibility to convert standard DX-90 datafiles (specifying a hydrographic chart) to a standard relational database (Postgres). In addition, the formal IHO (machine readable) definitions for colour and symbol definitions can be converted and stored in the same database. By combining these datasources by means of a virtual plotting engine implemented in the GEO^{++} system, which interprets the formal symbol definitions, and hand-coded symbology procedures (because a formal description is not yet specified by the IHO), an ECDIS display can be generated which conforms to IHO specifications.

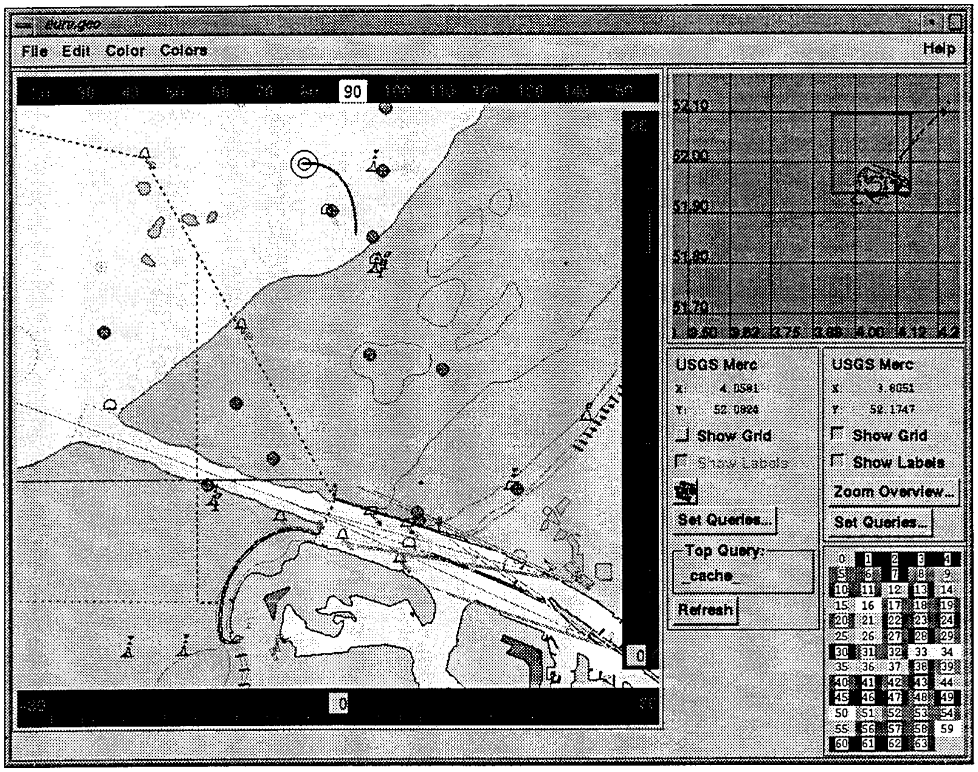

Fig. 2 GEO^{++} visualization of ECDIS data.

3 THE TRACK PREDICTOR PROTOTYPE

3.1 Basic premises

To realize accurate control of the ship's motions relative to the ship's surroundings, the navigator should have anticipating capabilities with respect to the ship's actual track in relation to the planned track. This anticipation minimizes the future error between the planned (desired) track and the expected position. The human behaviour to realize this minimization may be characterized by two complementary elements (Schuffel, 1986):

- *open-loop element*: the choice of manoeuvring actions on the basis of initial conditions and knowledge of the ship's manoeuvring properties and disturbances (cognitive anticipation),
- *closed-loop element*: corrections of manoeuvring actions on the basis of references. The references are used to judge the correctness of the actual sailed track with respect to the planned track (perceptive anticipation).

In his study of human control of ships in tracking tasks Schuffel showed that the open-loop element is not accurate, whereas the use of references (closed-loop element) may lead to accurate manoeuvring.

The track-prediction system, as under development by the Royal Navy Institute, aims at the support of the open-loop element of ship control. The emphasis of this approach lies on the use of the track predictor as an aid during the (short-term) planning of manoeuvres, on the

basis of a dynamical model of the own ship and disturbances (wind, current). From this perspective, the track predictor can be considered as a 'rehearsal' tool, rather than an 'on-line' manoeuvring tool. Consequently, during the execution of a manoeuvre possible deviations between the ship's actual and predicted track will have to be compensated by the master on the basis of error feedback (closed-loop element of ship control).
The present study focuses on the design of the user interface of the track-prediction system for the planning of course-changing manoeuvres. For this purpose it is assumed that for the final track-prediction system a mathematical model of the ship manoeuvring characteristics is available, which computes the ship displacement in time depending on rudder and propulsion parameters, in combination with the prevailing wind and current directions and strengths. For the design of the user interface a simplified version of this manoeuvring model was used (see Appendix C), in order to create the necessary context.

3.2 Predictor requirements

For the planning and preparation of ship voyages, in principle two levels can be discerned:

- on a global level, the desired path is defined by a collection of different waypoints, which specify where course changes have to be carried out.
- on a more detailed level, the course-changing manoeuvres are prepared. Especially for restricted waters or situations involving other traffic it is important that manoeuvres be carried out in a predictable way, independent of variations in the ship's dynamics and possibly without overshoot, in order to avoid groundings or collisions.

During a typical course-changing manoeuvre, according to Spaans (1979b), the following phases are completed (see Fig. 3):

a) selection of a rudder deflection at a wheel-over-point (A) that allows for a turning cycle with approximately the desired course line as a tangent (D-E);
b) selection of a counter-rudder deflection (B) to stop the turn rate so as to arrive at the desired course line with a zero turn rate (no overshoot);
c) corrective rudder deflections to adjust position, heading and turn rate errors (C). Possibly, for off-set compensation, for instance caused by wind influence, a stationary rudder value is required, the so-called 'permanent helm'.

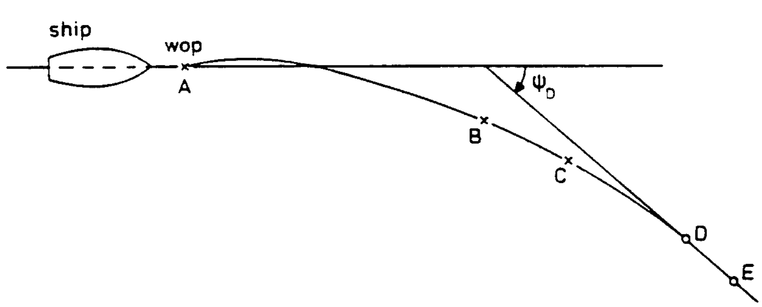

Fig. 3 Different phases of a course-changing manoeuvre: at the wheel-over-point (WOP) a rudder deflection initiates a turn, resulting in a circle with the desired course line (D-E) approximately as a tangent.

According to this description, the preparation of a course-changing manoeuvre involves:

- the determination of the *size* of the *rudder deflection* for turning, which directly influences the ship's track geometry (curvature), and the *timing* of this deflection, which is important to arrive with the appropriate course angle at the desired future track. To maintain this future track an additional course angle may be required to compensate for disturbances which cause an additional translation of the ship (e.g. *current*). An important additional parameter in this process is the ship's *forward speed* at which the manoeuvre is carried out.
- the determination of the *size* of the *permanent helm* for the compensation of the steady-state component of disturbances which cause an additional moment (e.g. *wind*).

Therefore, the output of the short-term planning process should be a specification of rudder and telegraph orders over position and/or time, which assists the master during the execution of a manoeuvre in deciding when and how to enter the different phases. In this process a track predictor could assist on the basis of a-priori knowledge of ship dynamics (the *manoeuvring model*) and disturbances *(wind and current data)*.

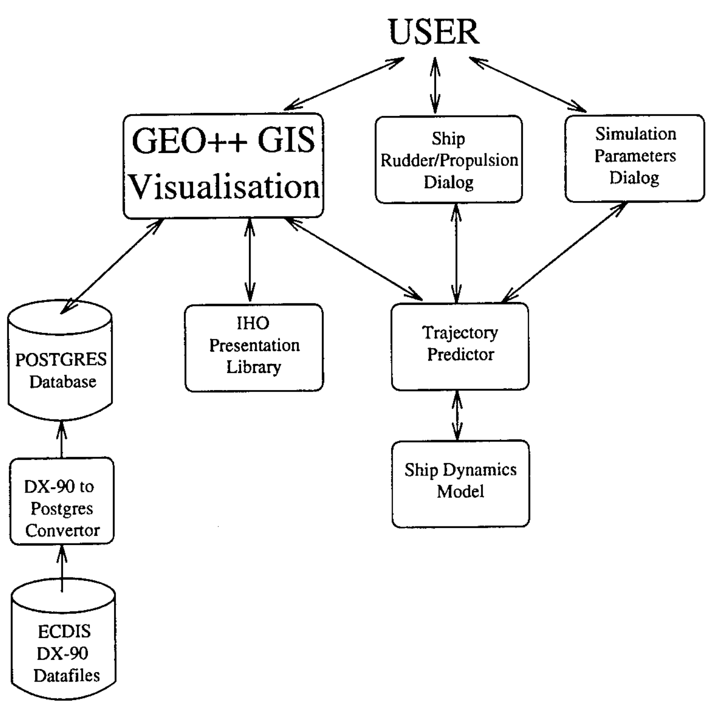

Fig. 4 The overall ECDIS/Track predictor architecture.

For the functional specification of the track predictor, the system architecture of Fig. 1 for the ECDIS visualization is extended with two modules which relate directly to the two-stage description of track planning (see Fig. 4):

- on the global level a *track planner* module should enable the user to specify the different *waypoints*, which together constitute the planned track, in combination with possible a-priori information on disturbances *(wind and current)*.
- on the more detailed level a *track predictor* module should enable the user to determine the required rudder and telegraph orders over position and/or time, in order to minimize

the expected error between the planned and the predicted track. In the following, this specification of rudder and telegraph orders over position are called *steering points.*

The output of both modules constitutes the overall track plan, consisting of a list of waypoints and steering points, which assist the master during the execution of the required manoeuvres. The next sections describe the design of these modules and the integration with the ECDIS system in more detail.

3.3 Track planner

The 'Track Planner' dialog window (shown in Fig. 5) allows the specification of global disturbances (wind and current) and the specification and placing of waypoints on the ECDIS chart. Furthermore, a list of steering points is presented which are determined on the basis of the 'Track Predictor' module (see § 3.4). We will now describe the components of this dialog.

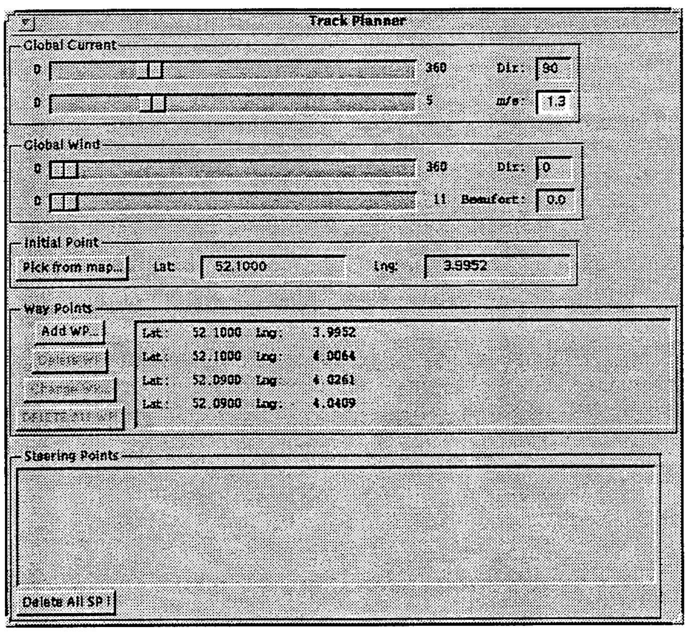

Fig. 5 The 'Track Planner' dialog window after the specification of the 'initial point' and waypoints for two 45° course-changing manoeuvres with a current of 1.3 m/s to the east (90°).

Global disturbances

- 'Global Current'

  The 'Track Predictor' module applies a simple uniform current field for the calculation of the predicted track. Sliders in combination with editable text fields placed to the right of each slider allow a setting of current direction (in degrees, '0' equals 'north') and speed (in meters per second). In the ECDIS Track Predictor prototype all sliders combined with an editable text field [from now on abbreviated as 'STP' ('Slider Text field Pair')] which behave according to the following user interaction rules:

- moving the slider with the left mouse button results in an update of the value in the text field situated to the right of the slider.
- a text field is selected by means of the standard OSF Motif interface: i.e. clicking in it with the left mouse button or by repeatedly hitting the TAB key until the desired text field is highlighted. In Fig. 5 the 'Dir' text field is currently highlighted. Typing a value into the text field results in simultaneous updates of the slider indicator situated left to it. This means that the user is free to choose between entering a value alpha-numerically or by moving the slider.

- 'Global Wind'
  This STP allows setting of the wind conditions.

Initial Point

The user may specify a starting position for the simulated vessel by hitting the **'Pick from map...'** button, after which the GEO^{++} information line asks the user to select a spot on the ECDIS chart with the left mouse button. After the user has picked this spot on the map, the selected Lat/Long position is displayed in the two text fields and the own ship symbol is shown on the selected location of the ECDIS chart.

Way Points

Waypoints are entered by hitting the **'Add WP...'** button, which activates a 'Way Points' dialog window. This dialog allows input of the waypoint location in a manner similar to the input of the *Initial Point*. Dismissing the dialog results in the waypoint symbol being added to the ECDIS chart at the specified location, to which a line is drawn from the previous specified waypoint. Furthermore, the 'Way Points' part of the 'Track Planner' dialog window shows a list of the entered waypoints to the right of the **'Add WP...'** button. A scroll bar is automatically added when the number of waypoints does not fit in the allocated space. Waypoints can be selected by clicking on a waypoint line in the list with the left mouse button. The user can also select waypoints from the ECDIS chart by clicking on the waypoint symbol with the left mouse button. This results in a highlight of the corresponding line in the waypoint list. If a waypoint has been selected in one of the two preceding ways, then the **'Delete WP'** and the **'Change WP...'** buttons are enabled. If no waypoint is selected then these buttons are disabled, i.e. grey. Hitting the **'Delete WP'** button deletes the selected waypoint from the list and removes the waypoint symbol from the ECDIS chart. Hitting the **'Change WP...'** button shows the 'Way Points' dialog window, with the STPs and Lat/Long fields filled in with the values from the selected waypoint, after which these can be changed. The **'DELETE ALL WP!'** button asks for a confirmation after which all waypoints are deleted from the list.

Steering Points

This part of the 'Track Planner' dialog window shows a scrollable list of all the logged steering points, as an output of the track predictor. See the next section for a more detailed description. The **'DELETE ALL SP!'** button asks for a confirmation after which all steering points are deleted from the list.

Fig. 5 shows the contents of the 'Track Planner' dialog window after the specification of the *global current*, *initial point* and *waypoints* for the preparation of two 45° course changes, which in Fig. 6 are presented on the ECDIS display. At this stage the manoeuvres can be prepared in more detail by using the track-prediction module, which finally provides the list of required steering points.

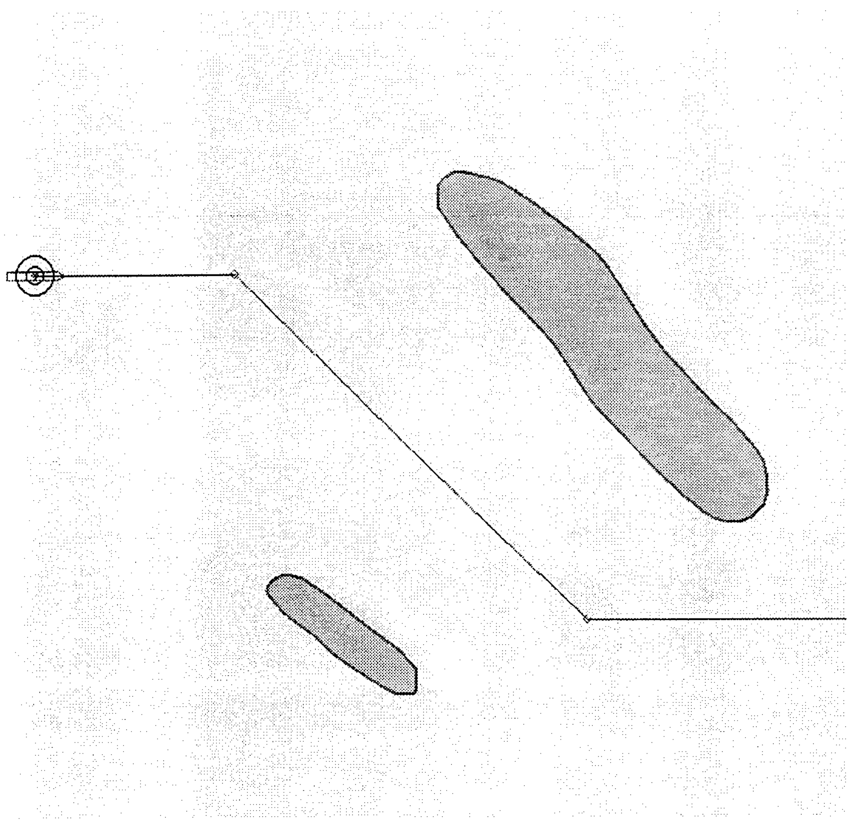

Fig. 6 The 'ECDIS' window after the specification of the 'initial point' and waypoints for two 45° course-changing manoeuvres, corresponding to the 'Track Planner' window in Fig. 5.

3.4 Track predictor

The required steering points are determined by means of the 'Track Predictor' dialog window shown in Fig. 7. The first part of this dialog window is used for the specification of trial steering parameters for a fast-time prediction model. Changes of these values are fed into this model and result in a direct visible feedback to the user in the form of a modified predicted track which is shown on the ECDIS chart. As an example, Figs 7 and 8 show the contents of the 'Track Predictor' and the 'ECDIS' window for the preparation of the second 45° course change corresponding to the track plan of Figs 5 and 6.

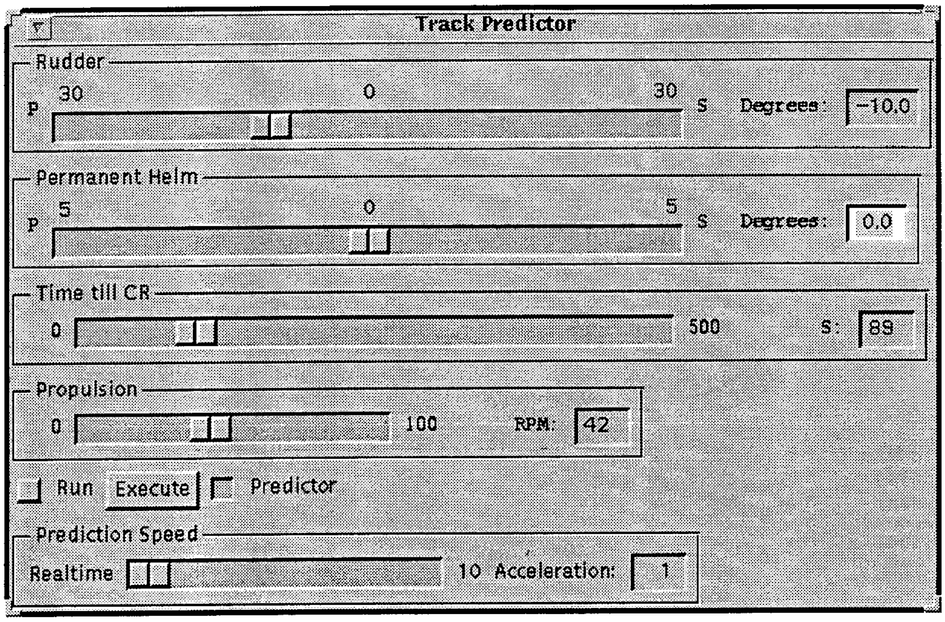

Fig. 7 The 'Track Predictor' dialog window during the preparation of the second 45° course change according to the track plan of Figs 5 and 6.

The trial steering parameters are:

Rudder The rudder to be set at the 'Wheel Over Point' is entered by means of this STP. The maximal rudder value is limited to 30°. For the example, the actual value is 10° port to prepare the 45° course change.

Permanent helm The stationary rudder value at the end of a manoeuvre, for instance for wind compensation. The maximal rudder value for this STP amounts to 5°. The actual value for the example is 0° (no wind compensation required).

Time till CR This STP allows the 'Time Till Counter rudder' to be specified. In the present simulation this time marks the end of a manoeuvre, after which the new permanent helm value is automatically activated. A delay between 0 and 500 seconds can be set. Note that a delay of 0 seconds disables this automatic setting, which results in a stationary turning circle. In the example the value is determined to be 89 seconds. This value was determined by increasing the TTC slider until the direction of the predicted track after the course change matched the new required direction according to the track plan (see Fig. 8).

Propulsion The Propulsion STP allows a setting of the propulsion system in RPM, in the example set to 42 rpm.

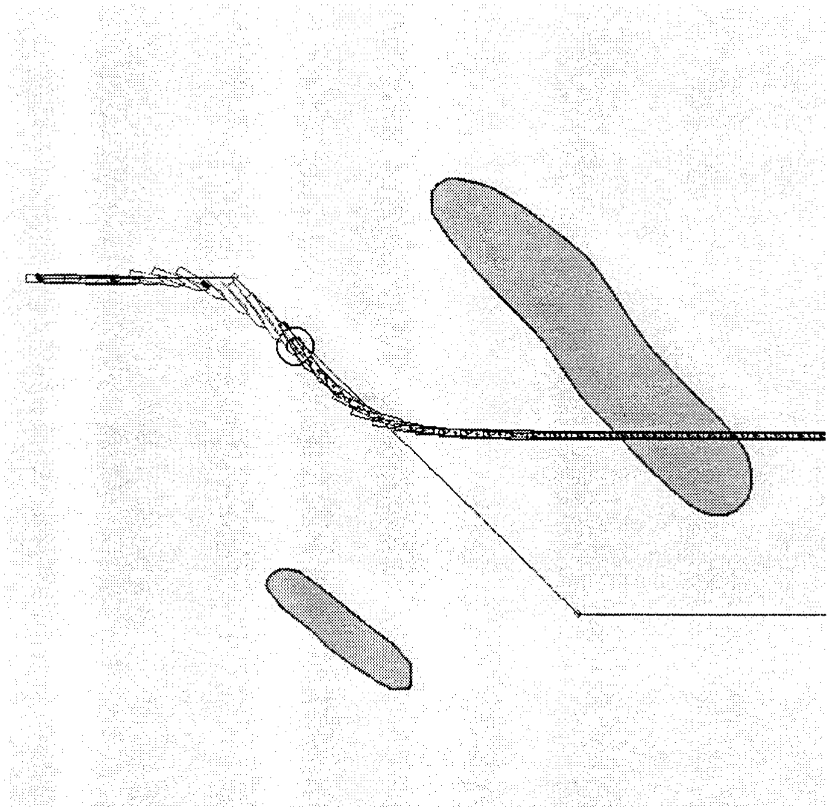

Fig. 8 The 'ECDIS' window during the preparation of the second 45° course change, corresponding to the 'Track Predictor' dialog window in Fig. 7.

The second part of the 'Track Predictor' dialog window serves as a control panel for the overall simulation. It contains the following buttons:

'Run': this toggle button allows the simulation to be suspended. When this button is not pushed (i.e. switched off), the clock is stopped and the movement of the simulated vessel is frozen until the button is pushed again. The speed of the simulation can be accelerated from real-time upto a factor 10 with the 'Acceleration slider'.

'Execute': the present trial steering parameters are stored as a steering point in the steering point list in the track planner, and fed into the simulation model.

'Predictor': this toggle button allows the predictor output to be switched on or off.

A 'Time till Counter Rudder' steering operation (i.e. the TTC slider has a non zero value) has the following behaviour:

- when the **'Execute'** button is pushed, the trial rudder value in the 'track predictor' dialog window is copied to the steering point list in the track planner window and is fed into the simulation model. The timing for this command may be determined by matching the predicted track with the planned track in the ECDIS window (Fig. 10). After the **'Execute'** command the button is temporarily disabled (i.e. drawn grey) until the TTC time has elapsed (Fig. 9).
- the 'Time till CR' slider and editable field are disabled during this period, so they cannot be adjusted by the operator until the TTC time is fully elapsed.

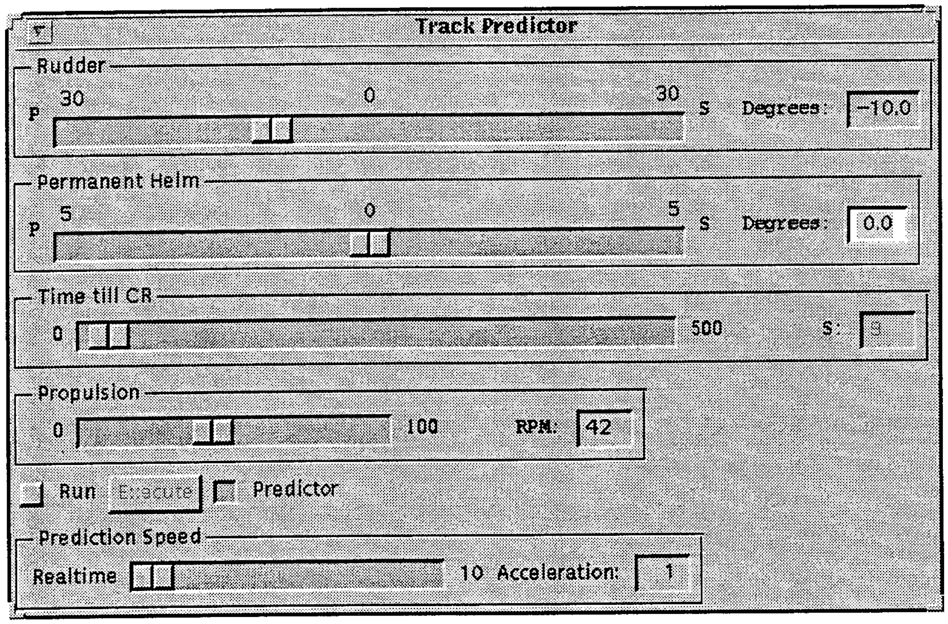

Fig. 9 The 'Track Predictor' dialog window during the simulated execution of the second 45° course change according to the track plan of Figs 5 and 6.

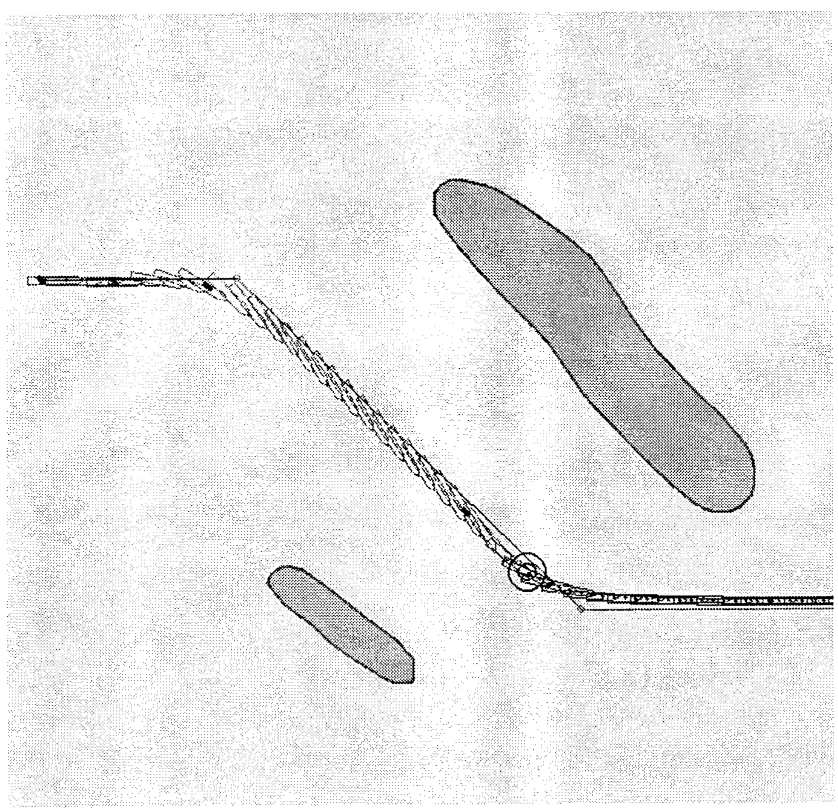

Fig. 10 The 'ECDIS' window during the simulated execution of the second 45° course change, corresponding to the 'Track Predictor' dialog window in Fig. 9.

- every second the 'Time till CR' slider and editable field are adjusted to show the remaining TTC time: i.e. the slider knob is moved left and the number in the editable field decreases (Fig. 9).
- when the TTC has elapsed, the 'permanent helm' value is automatically copied to the rudder value after which the TTC steering operation is completed.

Figs 11 and 12 show the final results for the detailed preparation of the two 45° course changes according to the global track plan of Figs 5 and 6.

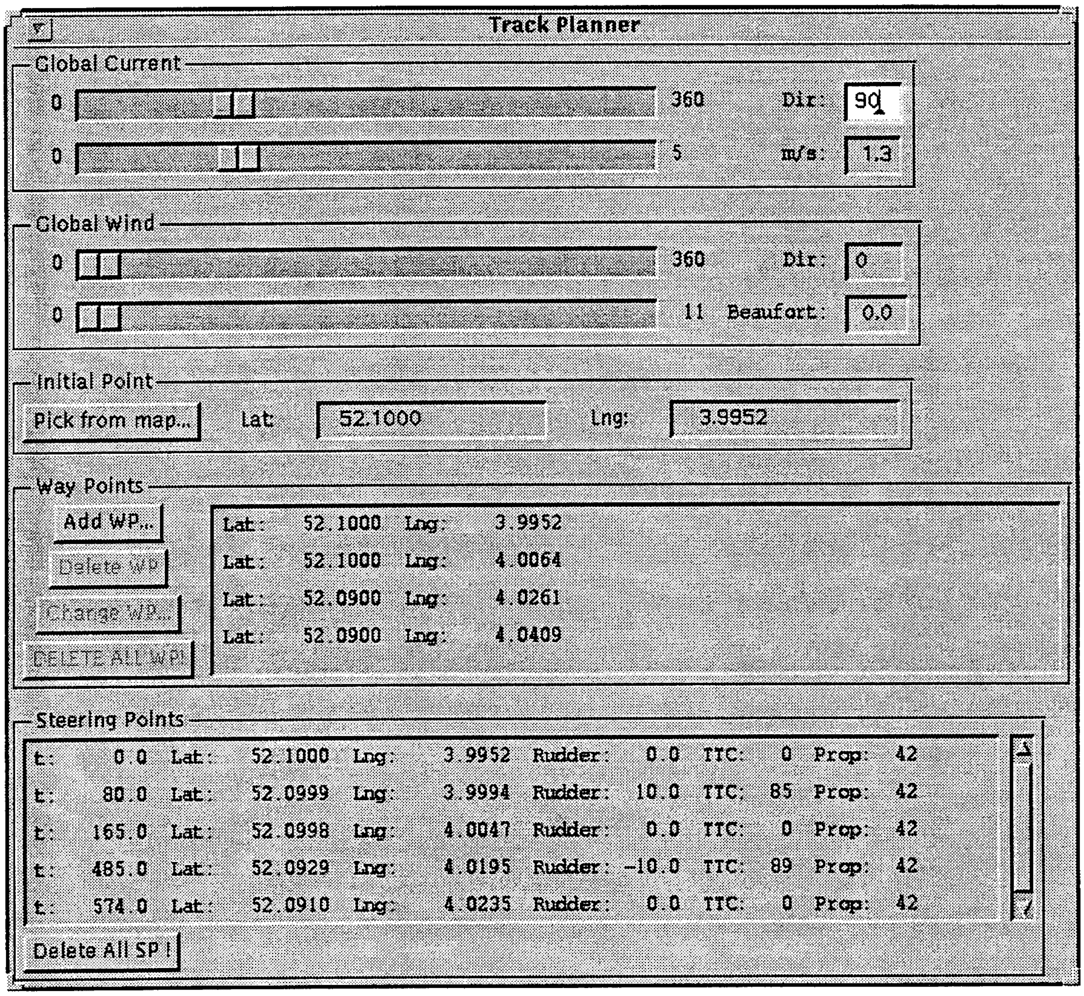

Fig. 11 The 'Track Planner' dialog window, showing the completed waypoint and steering- point lists for the preparation of the two 45° course changes according to the global track plan of Figs 5 and 6.

In the steering-point table, stored for each steering point are:
- the number of elapsed seconds since the start of the simulated voyage,
- the Lat/Long position at which the steering operation should be performed (marked as a rectangular steering-point marker on the ECDIS map),
- the rudder value in degrees,

- the TTC (Time Till Counter rudder) in seconds,
- the propulsion value in RPM.

During the actual sailing of the planned track, the master can select steering-point information from this list by clicking with the left mouse button on the rectangular steering-point markers on the ECDIS chart track log (see Fig. 12). The corresponding steering-point line in the table of the 'Track Planner' window (Fig. 11) will be highlighted when selected, showing the rudder and telegraph orders according to the detailed manoeuvring plan.

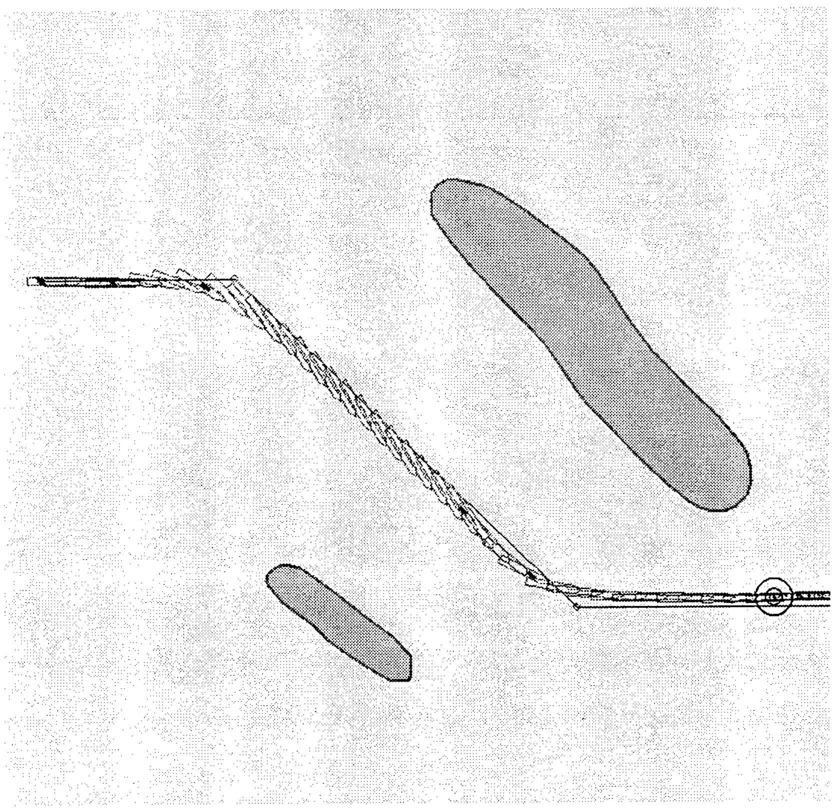

Fig. 12 The 'ECDIS' window after the preparation of the two 45° course changes, corresponding to the 'Track Planner' dialog window in Fig. 11.

3.6 Discussion

The proposed track-prediction interface demonstrates the feasibility to integrate a track-prediction system with an ECDIS system conforming to IHO specifications. The resulting track-prediction system assists the user in the track-planning process according to a two-stage model. The outcome of this process can be considered as a 'model inversion' of required waypoints (output of the first stage of track planning) to required steering actions (output of the second stage).

From a control point of view, as the model itself comprises only a-priori knowledge on ship dynamics and disturbances (wind and current), the corresponding steering actions can be considered as a feedforward element in the manoeuvring process to which feedback corrections will have to be added during the voyage execution for the compensation of

unknown disturbances. The extent to which these feedback corrections are required is largely determined by the quality of the prediction model, currently under development at the Royal Navy Institute, and a-priori knowledge on disturbances. Thus, besides the information presentation for track-planning purposes, for the final realization attention should also be focused on the information presentation during the execution of a manoeuvre, in order to assist the master in a fast detection of deviations between predictions and observations.

4 CONCLUSION AND SUGGESTIONS

On the basis of a two-stage description of track planning, a user interface has been designed for an integrated ECDIS/track-prediction system which assists the master in the preparation of manoeuvres. Both ECDIS display and track-prediction interface conform to existing specifications (IHO respectively OSF/Motif), so that the interface can be integrated with existing (commercial) ECDIS systems.

For further research, it is recommended to focus attention on the information presentation during the execution of a manoeuvre, in order to assist the master in a fast detection of deviations between predictions and observations on the basis of which feedback corrections can be determined.

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Soesterberg, 28 November 1995

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APPENDIX A: ECDIS DX-90 Definitions

ECDIS DX-90 Datafiles

The basis of the ECDIS prototype are DX-90 datafiles describing the objects on a nautical chart. DX-90 (IHO, 1991) is an international standard which lists all the different features (object types) and their attributes, and the format in which these are specified in the data files. Examples of features with some of their possible attributes are:

- *Point Features*

  lights:

  Attributes specify e.g. colour and blinking frequency.

  wrecks:

  Attributes specify e.g. ship name and wreck category.

  symbols:

  Attributes specify cartographic representation, e.g. a textual label and a rotation.
- *Sounding Features*

  A special kind of point feature with attributes specifying at least a location and a measured depth.
- *Line Features*

  depth contours:

  Attributes specify depth and a polyline (a number of locations composing a line).

  rivers:

  Attributes specify the name and a polyline. Note that in general rivers specified as a line will be small. Important rivers will be specified as an area.

  recommended track:

  Attributes specify an optional name, a track category, a polyline, etc.
- *Area Features*

  depth areas:

  Attributes specify a polygon (a number of locations composing an area) and a low and high tide depth.

  land regions:

  Attributes specify an optional name and a polygon.

  rivers:

  Attributes specify the name and a polygon.
- *Cartographic Features*

  texts:

  Attributes specify the text to be used, justification, orientation, spacing, character type (e.g. Univers or Times, either light, medium or bold and in a specified body size in pica points), etc.

  lines:

  Line symbols which cannot be derived from the corresponding real world object and its attributes.

areas:

Area symbols which cannot be derived from the corresponding real world object and its attributes.

symbols:

Point symbols which cannot be derived from the corresponding real world object and its attributes.

The ECDIS DX-90 data used for this prototype is the NL-122 sea chart. This data was provided by the Dutch Hydrographic Service. It covers the Eurogeul area: the entrance to the Rotterdam harbour.

DX-90 to Postgres Converter

The objects stored in the DX-90 datafiles are not directly suitable for storage in a relational database system. They first have to be converted to a format specifying each individual tuple for the relations (or less formally: tables) used in the Postgres database. The following relations (with their attributes) are used to store the DX-90 features:

- *Points:*

  ObjId

  Contains the object identification as assigned by the Hydrographic Service. E.g. `FE5AF 1059`.

  ObjL

  Contains the object label, e.g. `WRECKS`.

  Attr

  Contains the attribute information, e.g.
  `OBJNAMSperrbrecher147, CATWRK2, VERDAT2, QUASOU1, TECSOU6, VALSOU11.2, SCAMIN50000, SCAMAX50000, SORDAT7-JUL-1992, RECINDNHS-DIGI, RECDAT7-JUL-1992`
  . which lists a lot of specific additional information. See the official IHO documents for details.

  Pnt2

  Contains the position in geographical long/lat coordinates, e.g.
  `(4.086945, 52.026108)`.

  Geo_bbox

  Contains the minimal bounding box of the feature, e.g.
  `(4.08695, 52.0261, 4.08695, 52.0261)`
  This is used by GEO^{++} to zoom quickly to specific locations on the ECDIS map.

- *Soundings:*

  Soundings has the same attributes as the `Points` relation, with the exception off the addition of a `depth` attribute, e.g. `14.7`.

- *Lines:*

  Soundings is identical to the `Points` relation, with the exception that the `pnt2` attribute is replaced by a `pln2` attribute, containing a polyline in long/lat coordinates, e.g.
  `(374: 4.276665, 52.134411, 4.275726, 52.133949, ...)`

- *Areas:*
  Identical to the `Points` relation, with the exception that the `pnt2` attribute is replaced by a `pgn2` attribute, containing a polygon in long/lat coordinates.
- *Depth_Areas:*
  Identical to the `Areas` relation, but contains only features with object label `depare`, denoting depth areas. Each depth area has at least an attribute `drval1` and `drval2` containing the high and low tide depths.
- *Cartol:*
  Cartol has the same set of attributes as the `Lines` relation but it contains cartographic line features as described in § 2.3.
- *Cartop:*
  Containing cartographic point features and it has the same set of attributes as the `Points` relation.

Note that a relation `Cartoa` has not been implemented.

APPENDIX B: IHO Definitions

Colours

A part of the colour specifications (most of the *Bright Day* colours) is shown as an example in Table 1. The IHO colour specification contains the following information:

- The first column lists the symbolic colour code, e.g. `NODTA` is the colour to be used when no data is available for a specific area.
- The second column lists the colour, e.g. *moss green*.
- The next three columns list the x, y and *luminance* values in the CIE Colour Space.
- The last three columns list an approximation of the colour in RGB values.

Dictionaries

The presentation library contains dictionaries (lookup tables) which specify the visualization for points, line and area features. We will give a short explanation of the visualization specification for points only. The specifications for lines and areas are similar. The specification shown in Table 2 contains the following information:

- The first column lists the code of the object (point feature) class. E.g. `ACHARE` (the first row in the table) is an *Anchorage Area*.
- The second column lists the attribute combination, e.g. `BCNSHP2!MARSYS1!CATLAM1!` in row 16, means that this specific symbolization instruction for objects of type `BCNLAT` (beacon, lateral) is only valid when the point feature has all the listed attributes. In row 17 is an example of `BCNLAT` symbolization for a different set of attributes.
- The third column shows the symbolization instruction. It is either of the form `SY(XXX)` (e.g. `SY(HULKES01)`), which means to draw a specific symbol according to *symbol definition* `XXX` (see § 2.5.3); or of the form `CS(YYY)` (e.g. `CS(LIGHTS00)`), which means to draw a specific symbol according to the *symbology procedure* `YYY` (see § 2.5.4).
- The fourth column contains the display priority, a 4 digit integer number.
- The fifth and last column is optional. It specifies the viewclass membership, it is either empty, *standard* or *supplement*.

IHO Presentation Library Specifications

Table 1 Definitions of IHO Bright Day ECDIS Colours.

Code	*Color*	x	y	*Lum.*	*Red*	*Green*	*Blue*
NODTA	grey	0.28	0.31	25.35	167	142	126
CURSR	orange	0.53	0.41	28.04	255	107	19
CHBLK	black	0.28	0.31	0.00	0	0	0
...	...	...	...	...	...	...	...
CHWHT	white	0.28	0.31	93.12	255	255	217
SCLBR	orange	0.53	0.41	28.04	255	107	19
CHCOR	orange	0.53	0.41	28.04	255	107	19
LITRD	red	0.46	0.31	25.29	255	83	96
LITGN	green	0.29	0.60	55.88	0	237	41
LITYW	yellow	0.41	0.50	64.22	255	217	46
ISDNG	blue	0.17	0.15	22.27	0	129	206
DNGHL	red	0.49	0.31	25.29	255	67	90
TRFCD	magenta	0.28	0.15	21.68	255	29	189
TRFCF	magenta	0.28	0.24	48.47	255	165	199
LANDA	brown	0.34	0.40	66.71	255	221	132
LANDF	brown	0.46	0.46	15.84	192	105	21
CSTLN	black	0.23	0.16	0.00	0	0	0
SNDG1	grey	0.28	0.31	25.35	167	142	126
SNDG2	black	0.23	0.16	0.00	0	0	0
DEPSC	grey	0.28	0.31	25.35	167	142	126
DEPCN	grey	0.28	0.31	23.20	161	136	121
DEPDW	white	0.28	0.31	81.43	255	240	205
DEPMD	pale_blue	0.27	0.30	81.14	250	241	212
DEPMS	light_blue	0.25	0.30	72.38	192	237	206
DEPVS	medium_blue	0.24	0.29	65.69	168	228	205
DEPIT	moss_green	0.29	0.36	67.34	217	229	162
RADHI	green	0.28	0.48	29.92	0	173	82
RADLO	green	0.28	0.48	62.19	0	241	110
ARPA1	red	0.46	0.31	25.29	255	83	96
ARPA2	green	0.27	0.51	17.48	0	139	60
NINFO	orange	0.53	0.41	28.04	255	107	19
RES01	blue	0.17	0.15	22.27	0	129	206
RES02	yellow	0.41	0.50	64.22	255	217	46
RES03	grey	0.28	0.31	46.32	79	79	86
...	...	...	...	...	...	...	...
UNIF7	white	0.28	0.31	93.12	255	255	217

Table 2 Example of IHO Symbol visualization definitions.

Code	*Attributes*	*Symbol. Instr.*	*Priority*	*Viewclass.*
ACHARE	STATUS3!	SY(ACHARE01)	4000	SUPPLEMENT
ACHBRT		SY(ACHPNT01)	4000	SUPPLEMENT
ACHBRT	CATACH6!	SY(ACHBRT05)	4000	SUPPLEMENT
ACHPNT		SY(ACHPNT01)	4000	SUPPLEMENT
AIRARE		SY(AIRARE01)	1000	SUPPLEMENT
BCNCAR	BCNSHP0!	SY(BCNGEN01)	4000	
BCNCAR	BCNSHP1!	SY(BCNSTK01)	4000	
BCNCAR	BCNSHP3!	SY(BCNTOW01)	4000	
BCNCAR	BCNSHP4!	SY(BCNLTC01)	4000	
BCNISD	BCNSHP0!	SY(BCNGEN01)	4000	
BCNISD	BCNSHP1!	SY(BCNSTK01)	4000	
BCNISD	BCNSHP3!	SY(BCNTOW01)	4000	
BCNISD	BCNSHP4!	SY(BCNLTC01)	4000	
BCNLAT	BCNSHP0!	SY(BCNGEN01)	4000	
BCNLAT	BCNSHP1!	SY(BCNSTK01)	4000	
BCNLAT	BCNSHP2!MARSYS1!CATLAM1!	SY(PRICKE01)	4000	
BCNLAT	BCNSHP2!MARSYS1!CATLAM2!	SY(PRICKE02)	4000	
BCNLAT	BCNSHP3!	SY(BCNTOW01)	4000	
BCNLAT	BCNSHP4!	SY(BCNLTC01)	4000	
BCNSAW	BCNSHP0!	SY(BCNGEN01)	4000	
BCNSAW	BCNSHP1!	SY(BCNSTK01)	4000	
BCNSAW	BCNSHP3!	SY(BCNTOW01)	4000	
BCNSAW	BCNSHP4!	SY(BCNLTC01)	4000	
BCNSPP	BCNSHP0!	SY(BCNGEN01)	4000	
BCNSPP	BCNSHP1!	SY(BCNSTK01)	4000	
BCNSPP	BCNSHP3!	SY(BCNTOW01)	4000	
BCNSPP	BCNSHP4!	SY(BCNLTC01)	4000	
BCNSPP	CATSPM18!	SY(NOTBRD01)	4000	
BOYCAR	BOYSHP1!	SY(BOYCON01)	4000	
BOYCAR	BOYSHP2!	SY(BOYCAN01)	4000	
BOYCAR	BOYSHP3!	SY(BOYSPH01)	4000	
BOYCAR	BOYSHP4!	SY(BOYPIL01)	4000	
BOYCAR	BOYSHP5!	SY(BOYSPR01)	4000	
BOYCAR	BOYSHP6!	SY(BOYBAR01)	4000	
BOYCAR	BOYSHP7!	SY(BOYSUP01)	4000	
BOYINB		SY(BOYINB01)	4000	
...	...	...	...	...

Symbol Definitions

The IHO Presentation Library specifies the drawing definitions for symbols in a machine readable form. For each of the possible SY(XXX) instructions (see § 2.5.2) the library contains a definition. For example the definition for ACHARE:

```
SYMB     7SY00000
SYMD     39ACHARE01V00750007500033100412005840O550
CREF     6ECHGRF
VECT    119SPE;SW3;PU750,550;PD750,962;PU665,650;PD825,650;
           PU593,868;PD628,912;
           PD668,937;PD709,953;PD750,956;PD793,950;PD850,928;!
VECT     51PD881,906;PD903,875;PD915,850;PU593,868;PD584,850;!
```

The definition lines have the following meaning:

- SYMB: This line contains a symbol identifier code.
- SYMD: Contains information about the symbol:
  - The point feature for which this symbol is used (i.e. the name of the symbol).
  - The type of the symbol (either 'V' for vector or 'R' for raster). Currently only vector is used.
  - The dimensions of the symbol (i.e. width and height in units).
  - The upper left corner of the bounding box.
  - The rotation centre (pivot point) around which the symbol is rotated. Note that this point is also used as the hot spot for the picking operation (i.e. selecting an object by means of the left mouse button in GEO^{++}).
- CREF: The Colour Reference of this symbol: e.g. ECHGRF (for depth features), WLANDF for land features, etc.
- VECT: These lines specify the drawing instructions. These instructions steer a virtual plotting machine and they are separated by a ';' character. An example of used instructions:

  SP Selects a pen colour, e.g. SPW selects colour W. Colour A is the first colour in the colour table, B is the second colour, and so on.

  ST Selects a transparency mode. Mode 0 means a non transparent (opaque) drawing pen, mode 1 is a 25% transparent pen, mode 2 is 50% transparent and mode 3 is 75% transparent.

  PU Means lift the pen from the virtual paper and move it to the specified coordinates.

  PD Means place the pen on the paper and move it to the specified coordinates.

  SW Selects a pen width.

  PM Selects a pen mode, e.g. draw a dashed line.

  FP Fills a drawn area, i.e. draw a polygon.

  AA Draw an arc.

  CI Draw a circle with the specified radius.

Symbology Procedures

In the used version of the Presentation Library the Conditional Symbology Procedures were not supplied in machine readable form yet. Instead the specification is given in the form of

Nassi & Shneiderman diagrams (German Standard Institute, undated). Fig. 2 shows an example diagram for the visualization of depth areas.

The diagram shows the decision tree which, when traversed, results in the correct visualization of a depth area. Whether a specific branch is taken depends in most cases on the value of certain feature attributes.

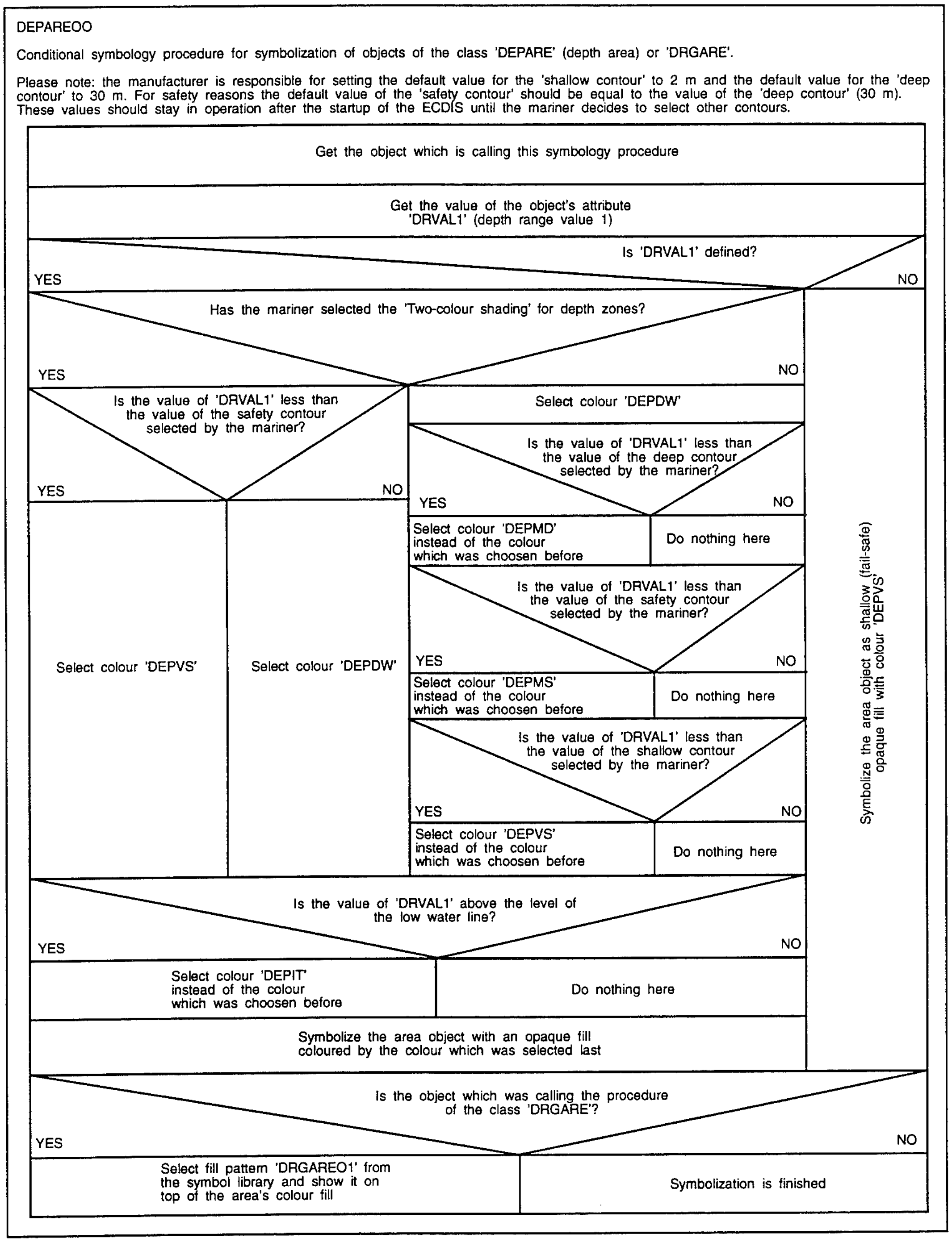

Fig. 2 A Nassi & Shneiderman diagram for depth areas.

APPENDIX C: Model of ship dynamics

C.1 Yaw dynamics

To simulate the ship's non-linear behaviour during course changing, characterized by a decrease in the forward speed in combination with an overshoot in the rate of turn for large course changes, a simple model for the yaw and forward speed dynamics was used based on the multivariable model as proposed by De Keizer (1977). Together with a simple relation for the ship's drift speed this yields the following equations:

$$\tau^{*}\cdot\frac{L}{u}\cdot\frac{\partial r}{\partial t} + \frac{u}{L}\cdot H(r^{*}) = K^{*}\cdot\frac{u}{L}\cdot\delta \tag{1}$$

$$\tau_u^{*}\cdot\frac{L}{u}\cdot\frac{\partial u^{*}}{\partial t} + H_u(u^{*}) = K_u^{*}\cdot r^{*2} \tag{2}$$

$$v = -\gamma^{*}\cdot L\cdot r \tag{3}$$

with r the ship's rate of turn, $u^{*} = \Delta u/U_0$ the relative loss of forward speed, v the drift speed, L the ship's length and δ the rudder angle.

C.2 Disturbances

Although current of a non-uniform nature may influence the ship's rate of turn, the most characteristic influence of current is considered to be a change of the ship's speed vector with respect to the ground which causes the direction of this speed vector to differ from the ship's heading. Therefore the influence of current is modelled as an additional term to the kinematic relationships:

$$\begin{aligned} u_x(t) &= u(t)\cdot\cos\psi(t) - v(t)\cdot\sin\psi(t) + U_{cx} \\ u_y(t) &= u(t)\cdot\sin\psi(t) + v(t)\cdot\cos\psi(t) + U_{cy} \end{aligned} \tag{4}$$

with ψ the ship's course angle and U_{cx} and U_{cy} the current speed components in x- and y-direction.

For simulation purposes the influence of the wind is modelled as an additional moment to the rudder, which is added to the term $K^{*}\cdot(u/L)\cdot\delta$ in Eq. (1). The size of this additional moment is made direction dependent according to:

$$N_w = N_{max}\cdot\sin(2\gamma_w) \tag{5}$$

with N_{max} depending on the wind force and γ_w the relative wind angle.

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Under contract to the Royal Netherlands Navy (contract no. A90/KM/332), the TNO Human Factors Research Institute investigates new user-interface concepts for ECDIS-based navigation support systems. On the basis of a two-stage description of track planning, a user interface has been designed for an integrated ECDIS/track-prediction system which assists the master in the preparation of manoeuvres. Both ECDIS display and track-prediction interface conform to existing specifications (IHO respectively OSF/Motif), so that the interface can be integrated with existing (commercial) ECDIS systems.
Regarding further research, it is recommended to focus attention on the information presentation during the execution of a manoeuvre, in order to assist the master in a fast detection of deviations between predictions and observations on the basis of which feedback corrections can be determined.

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